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Smart home technologies in everyday life: do they address key energy challenges in households?

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Smart home technologies (SHTs) enable new ways of using and managing energy in the domestic sphere. This paper interrogates their contribution to the ambitious carbon emissions reduction efforts required under the 1.5°C mitigation pathway set by the Paris Agreement and their suitability for energy poverty alleviation goals. In contrast to aspirational claims for a 'smart utopia' of greener, less energy intensive, and more comfortable homes currently present in market and policy discourses, we argue that SHTs may reinforce unsustainable energy consumption patterns in the residential sector, are not easily accessible by vulnerable consumers, and do little to help the 'energy poor' secure adequate and affordable access to energy at home.

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Introduction

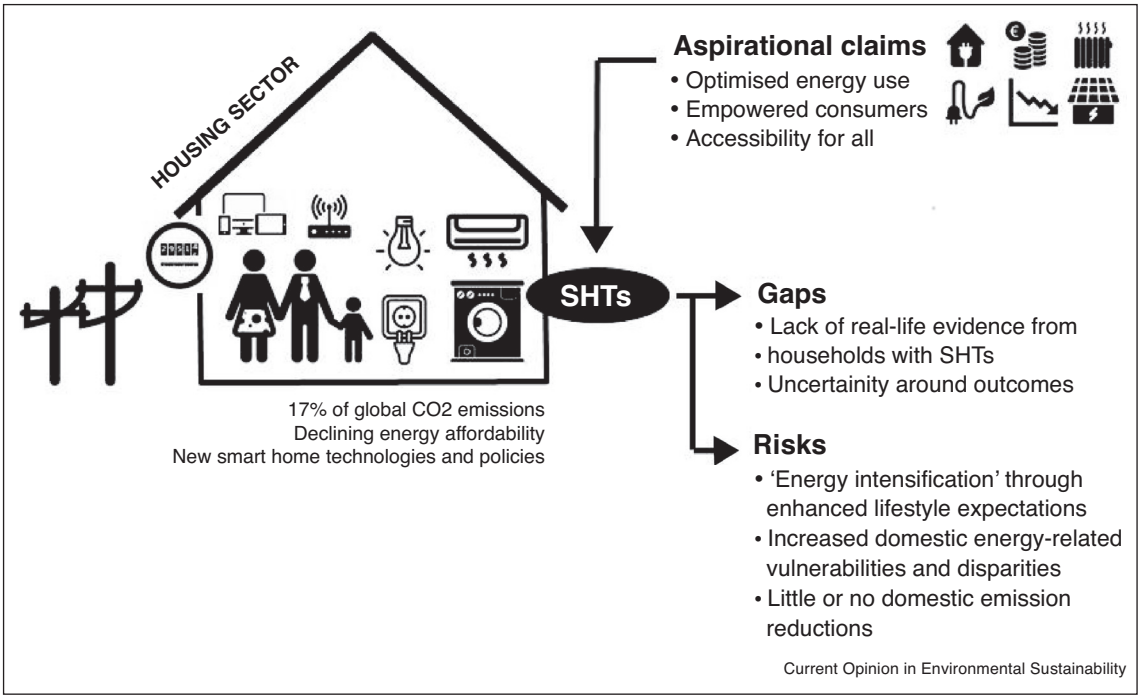
Aggressive mitigation is needed to avoid dangerous climate change as acknowledged by the 'well below 2°C above pre-industrial levels' target adopted during the 2015 COP21 Paris Agreement [1,2]. To meet COP21 agreement commitments, European and other developed countries must deliver significant reductions in final energy consumption including via more efficient use of energy in the buildings sector. The importance of reducing consumption and emissions in buildings is evidenced by the fact that this end-use sector contributes one third of global final energy use and energy-related CO_2 emissions [3]. Within that, the residential housing sector represents around 25% of global energy consumption and 17% of global CO_2 emissions [4].

At the same time, calls for a 'universal access to affordable, reliable and modern energy services' as stated in sustainable development goals (SDGs) [2] highlights the relevance of energy poverty as an issue of global significance closely related to the climate challenge. Understood as a condition in which households are unable to access socially- and materially-necessitated levels of domestic energy services, energy poverty is seen as a 'planetary problem' that refers both to lack of access and affordability of domestic energy [5]. Global data indicate that one in five people worldwide are not yet connected to the electricity grid and that almost 3 billion people rely on traditional fuels for cooking and heating [6]. In affluent regions such as the EU or Australia, a significant percentage of the population — though not a majority — suffer from excessive energy burdens, struggle to heat their home adequately or to pay their energy bills on time [7–9].

Addressing the interrelated global energy challenges of energy emissions and affordability requires a large scale transformation in how societies live, capture and provide energy. This shift is primarily aimed at significantly reducing the carbon (and other) footprints of final energy use and also needs to confront the deeply embedded underpinnings of energy-related injustice and deprivation [10,11,13–15]. Households are at the center of this double endeavor and are expected to play a more active role in managing and reducing their energy use with new 'tools' such as smart home technologies (SHTs) (Figure 1).

SHTs incorporate ICTs, sensors and networking capability to automatically and/or remotely control the operation of home appliances like lights, heating and air conditioning systems. This is usually done via smartphone apps, some other kind of touchscreen panel or interface, or through digital voice assistants (e.g. Google Home and Amazon Alexa). Initially developed for luxury 'smart homes' [12•], SHTs are now marketed more broadly as home electronics 'accessories' and devices, where they promise to 'significantly enhance domestic comfort, convenience, security and leisure whilst simultaneously reducing energy use through optimized home energy

Figure 1


HOUSING SECTOR
Aspirational claims
• Optimised energy use
• Empowered consumers
• Accessibility for all
SHTs
17% of global CO2 emissions
Declining energy affordability
New smart home technologies and policies
Gaps
• Lack of real-life evidence from
• households with SHTs
• Uncertainity around outcomes
Risks
• 'Energy intensification' through enhanced lifestyle expectations
• Increased domestic energy-related vulnerabilities and disparities
• Little or no domestic emission reductions
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Graphic abstract of the paper.

management' [13]. They are also being sold and operated in tandem with cognate devices such as smart meters, in-home displays (IHD) that are expected to help households visualize data and gain knowledge on their own energy consumption patterns.

The relevance of SHTs in future energy system imaginaries is made clear in the EU's 2015 Strategic Energy Technology Plan, which states the need to 'create technologies and services for smart homes that provide smart solutions for energy consumers' in order to 'give consumers in homes, companies and public administration control to optimize their energy consumption (and production)' [14]. The vision of a 'smart EU energy system' involves 'innovative service providers and start-ups delivering user user-friendly interfaces/tools for energy management [. . .] as part of a smart home service bundle' [15]. Along similar lines, the Australian Energy Market Commission says that 'smart appliances and smart meters will provide opportunities for consumers to better control and manage their electricity' [16].

Although energy efficiency and mitigation are not their main *raison d'être*, SHTs are anticipated to provide both residential emission reductions and associated benefits for households experiencing energy poverty, as the above excerpts indicate. In order to stimulate discussion on these issues, this paper critically assesses these claims by focusing on the lived experiences of households with SHTs in developed countries, where the market for SHTs is growing rapidly. In doing so, we provide a viewpoint informed by selected social science academic literature with a focus on two developed world regions (the EU and Australia) that are leading the deployment of SHTs worldwide. We focus specifically on two areas of this literature: first, reviews of SHTs that consider their implications for household energy consumption and energy poverty; and second, empirical studies of SHTs in real life household situations. This significantly narrows down the scope of our review, given that only 20 per cent of peer-reviewed research on 'smart home users' was recently found to be published in the social sciences [17]. A further limitation noted by Paetz [18] is that 'up to now, hardly anyone has seen, experienced or lived in an environment that offers the full range of ICT-based energy management solutions'.

With this focus in mind, we continue by providing an overview of the ways SHTs shape domestic energy use and daily routines followed by an evidence-based assessment of their contribution to climate change mitigation and their role in addressing energy-related vulnerabilities and inequalities. The paper concludes with critical reflections on the scope for SHTs to address these energy challenges.

Understanding how SHTs shape everyday life

As part of a broader trend in Internet-enabled consumer electronics and infrastructures (e.g. the 'Internet of

Things'), SHTs are increasingly referred to as part of a 'digital revolution' or 'next great disruptor' [19]. In the words of Saskia Sassen (digital) technologies 'can be constitutive of new social dynamics, but they can also be derivative or merely reproduce older conditions' [20•]. There are two energy-related 'social dynamics' expected to undergo a major shift facilitated by the incorporation of SHTs into the everyday lives of householders. The first assumes that through smart devices, households will be better informed and empowered in the changing competitive energy market by providing incentives to make the better choices about when to consume energy (e.g. cost-reflective pricing) and more accurate, visible and up-to-date information about their electricity consumption (e.g. consumption apps and portals) [13,21]. The second common proposition focuses on automating demand response through 'enabling' smart home technologies, therefore relying far less on active consumer participation [22]. This approach assumes that such technologies mostly operate 'in the background', and focuses on 'setting and forgetting' large appliances or other household energy demand.

When the uptake of smart home technologies does not deliver satisfactory results, prevalent interpretations speak of 'seemingly irrational, yet predictable tendencies' in consumer behavior and resort to explanatory devices like cognitive biases such as the 'knowledge-action gap' and 'value-action gap' [23,24]. In contrast, we argue that both of these propositions are problematic because they tend to assume an artificial separation between people and technology, and position energy consumers as either 'active' or 'passive'. Instead, we follow social scholars of technology who demonstrate how technologies are constantly influencing and shaping the way we live, even when they are designed without this intention [25•,26••].

A critical assessment of SHTs in real-life

Claims of 30% energy savings from SHTs have been made by smart home industry proponents [27] but evaluation of energy outcomes of SHTs 'in the wild' is lacking. In a recent review by Darby [12•] notes the scarcity of evaluations 'of smart home initiatives in terms of end-use efficiency' and the 'striking contrast between the many research papers that estimate potential benefits from smart appliances/systems on the basis of simulations or trials in carefully controlled laboratory conditions and the handful that report on measured performance and acceptability in real-life conditions'.

The dearth of such studies is evidenced by the fact that one of the few real-life investigations of home automation use over an extended period was conducted in 2007 with orthodox Jewish families relying on the automated control of household appliances to observe the Sabbath. Monitoring energy savings was neither the aim nor a noted outcome of the analysis [28]. More recently, results from Hargreaves *et al.*'s short-term (9-month) field trial of SHTs with 10 households in the UK, concluded that 'there is little evidence that smart home technologies will generate substantial energy savings and, indeed, there is a risk that they may generate forms of energy intensification' through pre-warming domestic spaces before residents come home, raising comfort expectations or encouraging the adoption of additional energy-using technologies [29••]. A range of SHTs were trialed in this study, and the authors also found that, rather than being easily integrated into home life, SHTs required a substantial amount of learning. Despite most trial households including occupants who worked in the IT/engineering/technical fields, and even though the SHTs were professionally installed for households, most limited their use of the SHTs to more basic functions as the trial progressed. Few households 'domesticated' the technologies which raises further doubts about whether the energy savings expectations for SHTs can be met in a domestic setting.

These observations align with the findings from our Australian project *Smart Home Control: Exploring the potential for enabling technologies in households*, which conducted a trial of basic 'off-the-shelf' SHTs in a range of households including low-income households and households who may be less engaged with energy issues and technology. Forty households volunteered to receive and try 'easy' self-install smart light bulbs and smart plugs (which can be used to automate or remotely control the operation of home appliances). Among these, one quarter did not attempt to install them, a further quarter tried but could not get the SHTs to work. Of the remaining households that did install the devices, half of these abandoned using them. Of the 10 households that did use the devices over several months, they were often looking for additional lifestyle and wellbeing benefits (such as increased security/safety or ambience, preheating or precooling of homes, assistance with parenting challenges) rather than energy saving opportunities, and energy intensification was reported by some [30•]. This finding is consistent with the role of the smart home industry in promoting energy-intensive lifestyle aspirations that increase demand and undermine savings, as seen in our past analyses [31,32]. Darby has also made this observation, noting that as new energy intensive practices arise, partly as a result of the introduction of new technologies into the home, focusing on energy savings 'often turn[s] out to be steps taken down an upward-moving escalator' [33].

Zooming in on more specific smart home devices, such as smart thermostats, provides further insights into how high expectations of energy benefits can be unfulfilled in real-life settings. Similar to when programmable thermostats were introduced in the 1990s, smart thermostats were expected to generate average energy savings of 20–30% on heating and cooling [34]. As observed by Malinick *et al.* [35], energy savings from thermostat control technologies

tend to be calculated using a high energy baseline such as running the home at a 'climate control' setpoint temperature throughout the year. However, most households in Australia (and many other countries) actively and manually manage their heating and cooling use by turning it down or off when away from the home or asleep, and not using it at all during 'mild' weather [36,37]. As such, energy savings from smart thermostats are likely to be far lower in a more representative cohort. One prominent smart thermostat manufacturer in the US significantly revised its average energy savings estimates from (20 to 10–12%), and noted a significant variability in consumption outcomes. In fact, increased gas use after installing the thermostat was found in around one-third of households — and in about 8% of households gas use was 20–40% higher [38].

Even if no definitive conclusions can be drawn yet from the limited studies available, skepticism about the energy saving potential of SHTs is justified by these cases and additional references [25•,39]. In the words of Sarah Darby [12•]:

> 'In the absence of comprehensive in-use evaluation, it is probably safe to assume that the net effect of home automation on fuel and electricity consumption is neutral or negative: if it were positive, manufacturers would surely be publicizing this. At the same time, the striking shortage of published smart home evaluations suggests an unwillingness to address the possibility that they might only 'work' for small subsets of the population [...] It does not offer a credible response to the wicked problem of environmental harm arising from modern energy services'.

In summary, the limited evidence available suggests that SHTs may promote and circulate lifestyle expectations that *increase* energy consumption in the home and outweigh potential efficiency and automation benefits. Additional considerations that may undermine emission reduction ambitions for SHTs include their embedded energy and the use of transmitted data and streamed content, which relies on remote data servers (the energy requirements for which are rapidly increasing) [40].

Smart home technologies through the lens of social equity

Dominant visions relying on 'smart utopia' imaginaries see household energy consumers as narrowly rational, utility maximizing and technologically literate individuals caricatured by Strengers as a 'Resource Man' [25•,41]. Following this critique, SHTs are not being delivered on a 'tabula rasa' of equally capable and resourced citizens and consumers but, on the contrary, map onto very uneven socio-economic landscapes. Thus there are concerns around the suitability of SHTs and their services for less privileged households, which as Balta-Ozkan *et al.* argues calls for policy leadership to 'make sure that people are not disadvantaged and that no further divisions are created in general' as the roll out of smart energy systems progresses [42].

In particular, issues around the reliability, interoperability, administration, and installation and maintenance costs of SHTs have been described by Balta-Ozkan *et al.* as 'social barriers' to their uptake, and have special significance among vulnerable households for whom the practicalities of the installation and daily use of these devices is particularly burdensome and likely to be a deterrent for their adoption [43]. Similar issues appeared in our *Smart Home Control* project trialing SHTs in Australian households [30•], which sought to understand if and how these technologies would be used in less 'tech-savvy' households, low-income households, and households who may be disengaged from energy issues. These included households with children, households headed by women and older households — in other words, the types of households often underrepresented or missed in technology trials [30•].

Such households face increasing complexity and expectations as smart technologies are rapidly deployed throughout countries in the developed world. For example, smart meters enable energy utilities to charge higher prices for electricity used at peak times and households are expected to use SHTs to shift timing of appliance use to take advantage of lower 'off-peak' electricity tariff times [16,44]. However, the S*mart Home Control* project and other research highlights a range of equity issues with these assumptions.

Firstly, it is difficult for consumers with relatively stable daily routines (e.g. households with children) to avoid peak time rates under variable pricing scenarios enabled by smart technologies [45,46]. The constitution of these routines inevitably relates to gender, a critical element in the equity analysis, as 'men in households have typically taken responsibility for managing the physical, infrastructural and large financial commitments whilst women have jurisdiction over the furnishings, fittings, domestic routines and childcare' [21]. Secondly, the installation of SHTs usually requires technology skills and enthusiasm. In our *Smart Home Control* project, men and technology enthusiasts were more likely to try the devices and very few people over 55 years of age were interested or able to use them. A third potential issue relates to accessibility and familiarity with supporting technology and infrastructure. In our study, households who were at risk of energy vulnerability were keen to try SHTs but were often prevented from doing so because they did not own the more expensive and recent smartphones, or have sufficient Internet capacity needed to use SHTs. This

inequity in access implies that financially constrained households will not be equally able to participate in technology-enabled energy management and could be further disadvantaged. This issue of 'digital exclusion' is already recognized in other spheres, for example, education and employment opportunities [47], but has not been sufficiently addressed in energy policy, which assumes universal access to (and ability to understand and use) home technology and network infrastructure. Finally, our study identified that households attracted to perceived benefits from technologies may be at risk of spending more money purchasing SHTs than they recoup through energy reductions or shifting, a situation which puts financially vulnerable households at greater risk [30•].

Conclusions

Confronting aspirational claims about the role of SHTs in delivering significant domestic energy savings, this paper has shown that there is little evidence that this will transpire as anticipated. While SHTs may have the capability to reduce energy use through efficiency improvements and automation features, there is a range of additional services these technologies provide which can increase energy consumption, thus undermining climate change mitigation targets, and are not well suited for energy poverty alleviation ambitions. Despite the lack of real-life evidence drawn from regular households and the uncertainty surrounding their outcomes, the few in-home studies identified point towards some risks including that these technologies inadvertently raise lifestyle expectations or sustain energy intensive ways of life (e.g. smart thermostats promoting climate controlling home environments), and that they may be neither fit nor accessible enough to vulnerable households.

SHTs may also increase domestic energy-related vulnerabilities and disparities between households, thereby exacerbating energy poverty, as the benefits they provide may be less available to disadvantaged households who do not have up-to-date smartphones and/or reliable Internet services. Additionally, SHTs enable and justify energy policy shifts towards more cost-reflective tariffs (on the assumption that households will use SHTs to respond) that may exacerbate energy poverty in vulnerable households whose energy consumption is not 'flexible' in response to price signals. Consequently, we call for a thorough reexamination of the alleged 'neutrality' of smart technologies [21] from a social equity perspective, and for further investigation of their role in potentially consolidating unsustainable domestic energy use patterns.

On the basis of our assessment, we argue that more research is needed to critically interrogate the claims for SHTs in real-life settings. This research would benefit from some of the conceptual lenses applied in this short review, such as the understanding that technologies and people co-shape each other in unintended ways, and the notion that SHTs are not just relevant for individual energy users but have impacts on communities and societies as a whole.

Conflicts of interest

None.

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